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'WILSN-CL' USERS GUIDE: IBM-PC/AT COMPUTER CALCULATION OF DIAMETRIC TUNNEL CLOSURE USING THE NCB WILSON FORMULA

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'WILSN-CL' USERS GUIDE: IBM-PC/AT COMPUTER CALCULATION OF DIAMETRIC TUNNEL CLOSURE USING THE NCB WILSON FORMULA

by

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SUMMARY

The report describes the program 'WILSN-CL' which calculates diametric tunnel closure based on a formula developed by Dr. A.H. Wilson of the National Coal Board, U.K. The program is written in BASIC A Version 3.10 for an IBM-PC/AT.

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GUIDE DE L'UTILISATEUR 'WILSN-CL': CALCUL SUR ORDINATEUR IBM-PC/AT DE LA FERMETURE DIAMÉTRALE D'UN TUNNEL EN UTILISANT LA FORMULE DE WILSON NCB

par

P. Kearney* et T.R.C. Aston**

RÉSUMÉ

Le rapport comprend une description du programme 'WILSN-CL' qui permet de calculer la fermeture diamétrale d'un tunnel selon la formule développée par M. A.H. Wilson du National Coal Board, R.-U. Le programme est écrit en langage BASIC A, Version 3.10, pour un ordinateur IBM-PC/AT.

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INTRODUCTION

Work undertaken by the National Coal Board in the United Kingdom (1) has established an equation which relates the strength of a tunnel lining and the surrounding rock properties to the amount of closure experienced by the tunnel, equation 1:

$$c = d\frac{(1+v)}{E}\left(\frac{(k-1)q+\frac{\sigma}{f}}{(k+1)}\right)\left(\frac{2q-\frac{\sigma}{f}}{(p+p^1)(k+1)}\right)^{(2+\varepsilon)/(k-1)} \qquad \text{Eq 1}$$

which can be approximated to:

$$c = d\frac{4}{\sigma}\left(\frac{(k-1)q+\frac{\sigma}{f}}{(k+1)}\right)\left(\frac{2q-\frac{\sigma}{f}}{(p+0.1)(k+1)}\right)^{2.2/(k-1)} \times 10^{-3} \qquad \text{Eq 2}$$

A full listing of the parameters in equations 1 and 2 is given in Table 1.

Equations 1 and 2 are based on the assumption that the roadway is circular in cross-section and driven through homogeneous isotropic rock. It is also necessary to assume plain strain conditions and that the virgin horizontal and vertical stresses are equal.

In practice, although the idealised conditions seldom occur, equations 1 and 2 can provide a very useful method for calculating a first order approximation of the probable tunnel closure. Similarly, if the tunnel under consideration is not circular in shape, but the width/height ratio is close to 1, the yield/elastic zone boundary will be roughly circular in shape and the equations can be applied to square and arch-shaped roadways.

To simplify the use of equations 1 and 2, a user friendly computer program, 'WILSN-CL' was developed at the Cape Breton Coal Research Laboratory to predict the diametric closure of tunnels.

The 'WILSN-CL' program is written for use on an IBM-PC/AT microcomputer using the BASIC A Version 3.10 language. The program is conveniently run using a 360 kB diskette and an EPSON FX100 dot matrix printer. The user is expected to be familiar with the use of microcomputers and the concept of tunnel closure.

$$c = d\frac{(1+v)}{E}\left(\frac{(k-1)q+\frac{\sigma}{f}}{(k+1)}\right)\left(\frac{2q-\frac{\sigma}{f}}{(p+p^1)(k+1)}\right)^{(2+\varepsilon)/(k-1)}$$

Equation 1

$$= d\frac{4}{\sigma}\left(\frac{(k-1)q+\frac{\sigma}{f}}{(k+1)}\right)\left(\frac{2q-\frac{\sigma}{f}}{(p+0.1)(k+1)}\right)^{2.2/(k-1)} \times 10^{-3}$$

Equation 2

c = Diametric Closure (mm)
d = Driven Diameter (m)
[1]v = Poisson's Ratio
[1]E = Young's Modulus (MPa)
k = Triaxial Stress Factor
q = Cover Load (MPa)
σ = Laboratory Uniaxial Compressive Strength of Rock (MPa)
p = Lining Resistance (MPa)
f = Factor Relating Laboratory Strength to In Situ Strength (including degree of fracturing/jointing)
[2]p^1 = Augmentation of Lining Resistance caused by 'Cohesion' of the Yield Rock (MPa)
[3]ε = Expansion Factor for the Yielded Rock

1) If v and E unknown, then $\frac{(1+v)}{E} = \frac{4}{\sigma} \times 10^{-3}$ (Ref. 1)

2) If p^1 unknown, assume a value of 0.1 MPa (Ref. 1)

3) If ε unknown, assume a value of 0.2 (Ref. 1)

Table 1 - Equation nomenclature

A source listing of the program (Appendix A) is given along with examples of the output format.

PROGRAM USE

The 'WILSN-CL' program has a user friendly menu style operating system.

It is important to note that the input data is required in metric units (metres and MPa).

RESULTS

Two case histories (1) are presented to illustrate the use of the 'WILSN-CL' program.

LINING FAILURE AT ABERNANT COLLIERY

At Abernant Colliery in South Wales, U.K., two tunnels were driven at a depth of 720 m in highly faulted ground, composed mainly of distorted weak mudstones. The initial lining was reinforced concrete about 1 m thick, but this quickly broke up. A second lining strengthened with ring beams of double reinforced concrete, 2 m thick was therefore installed. However, this also failed, and success was not achieved until the tunnels advanced beyond the area of broken ground and the strata allowed to stablise. A considerable volume of strata was removed in the intervening period.

Input data:

$k = 3$

$f = 7$

$p = 0.05$ MPa

$q = 18$ MPa

$d = 9$ m

v and E unknown, therefore $\sigma = 10$ MPa

The predicted closure of about 3 m, Table 2, was close to the order of the strata movement actually seen.

DIAMETRIC CLOSURE CALCULATIONS

LOCATION DESCRIPTION:LINING FAILURE AT ABEMANT COLLIERY

DATA COLLECTION DATE:

REPORT GENERATION DATE:08/06/87

THE DRIVAGE DIAMETER IS 9 METERS

THE TRIAXIAL STRESS FACTOR IS 3

THE LABORATORY DETERMINED, UNCONFINED
STRENGTH OF THE ROCK IS 10 MPa

THE POISSON'S RATIO IS 0

THE MODULUS OF ELASTICITY IS 0 MPa

THE COVER LOAD IS 18 MPa

THE LINING RESISTANCE IS .05 MPa

THE FACTOR RELATING LABORATORY STRENGTH
TO IN SITU STRENGTH IS 7

THE AUGMENTATION OF THE LINING RESISTANCE
CAUSED BY COHESION OF THE YIELDED
ROCK IS .1 MPa

THE EXPANSION FACTOR IS .2

THE PREDICTED CLOSURE IS 2911.176 MILLIMETERS

Table 2 - Predicted diametric closure, Abernant Colliery

DIAMETRIC CLOSURE CALCULATIONS

LOCATION DESCRIPTION:DRIVAGE STABILITY AT DAWDON COLLIERY

DATA COLLECTION DATE:

REPORT GENERATION DATE:08/06/87

THE DRIVAGE DIAMETER IS 4 METERS

THE TRIAXIAL STRESS FACTOR IS 3.5

THE LABORATORY DETERMINED, UNCONFINED
STRENGTH OF THE ROCK IS 70 MPa

THE POISSON'S RATIO IS 0

THE MODULUS OF ELASTICITY IS 0 MPa

THE COVER LOAD IS 12 MPa

THE LINING RESISTANCE IS .2 MPa

THE FACTOR RELATING LABORATORY STRENGTH
TO IN SITU STRENGTH IS 3

THE AUGMENTATION OF THE LINING RESISTANCE
CAUSED BY COHESION OF THE YIELDED
ROCK IS .1 MPa

THE EXPANSION FACTOR IS .2

THE PREDICTED CLOSURE IS 1.455975 MILLIMETERS

Table 3 - Predicted diametric closure, Dawdon Colliery

DRIVAGE STABILITY AT DAWDON COLLIERY

A 4 m diameter drivage was undertaken at Dawdon Colliery in a strong siltstone at a depth of 480 m. The measured laboratory strength of the siltstone was 70 MPa and the triaxial stress factor, 3.5. A visual inspection showed the siltstone to be almost completely free of joints and/or bedding and an in situ factor, f = 3 was therefore selected. The drivage was supported by circular steel rings with an estimated resistance of 0.2 MPa.

Input data:

$k = 3.5$
$f = 3$
$p = 0.2$ MPa
$q = 12$ MPa
$d = 4$ m

v and E unknown, therefore $\sigma = 70$ MPa.

Although about 2 mm of movement was predicted, Table 3, no visible strata movement was discernable and the roadway remained in perfect condition throughout the siltstone unit.

REFERENCES

1. Wilson, A.H. 'The stability of underground workings in the soft rocks of the coal measures'; Int. J. of Mining Engineering; Vol. 1, No. 2, pp. 91-187; 1983.

APPENDIX A

```
10 REM  ************************************************************
20 REM  *                                                            *
30 REM  *                                                            *
40 REM  *                    DIAMETRIC CLOSURE                       *
50 REM  *                    -----------------                       *
60 REM  *         THIS PROGRAM CALCULATES THE DIAMETRIC CLOSURE      *
70 REM  *                    OF A TUNNEL DRIVAGE                     *
80 REM  *                                                            *
90 REM  *         SOME BASIC ASSUMPTIONS ARE:                        *
100 REM *            A) THE DRIVAGE HAS A CIRCULAR CROSS SECTION     *
110 REM *            B) IT IS SURROUNDED BY HOMOGENEOUS ISOTROPIC ROCK *
120 REM *            C) PLANE STRAIN CONDITION EXIST; AND            *
130 REM *            D) VIRGIN HORIZONTAL AND VERTICAL STRESSES      *
140 REM *                          ARE EQUAL                         *
144 REM *                                                            *
147 REM ************************************************************
150 PRINT
160 PRINT "                        CALCULATING DIAMETRIC CLOSURE"
170 PRINT "                        -----------------------------"
180 PRINT
190 PRINT "ALL THE UNITS FOR THE FOLLOWING FORMULA MUST BE GIVEN IN"
200 PRINT "METERS OR MPa , WHATEVER IS APPROPRIATE FOR EACH VALUE."
210 PRINT "------     ---"
220 PRINT
230 PRINT "INPUT THE DRIVAGE DIAMETER BELOW"
240 PRINT
250 PRINT
260 INPUT "THE DRIVAGE DIAMETER IS";D
270 PRINT
280 PRINT"_____________________________________________________"
290 PRINT
300 PRINT
310 PRINT "THE TRIAXIAL STRESS FACTOR IS A RELATIONSHIP BETWEEN"
320 PRINT "    ----------------------"
330 PRINT "COMPRESSIVE STRENGTH AND CONFINING PRESSURE"
340 PRINT
350 PRINT
360 PRINT
370 PRINT "IF THE INTERNAL ANGLE OF FRICTION OF THE ROCK IS KNOWN,"
380 PRINT "THE TRIAXIAL STRESS FACTOR CAN BE CALCULATED BY USING "
390 PRINT "THEN FOLLOWING FORMULA : K=[1+SIN N)/(1-SIN N)"
400 PRINT
410 INPUT "IS THE INTERNAL ANGLE OF FRICTION KNOWN;ANSWER Y OR N";Z$
420 PRINT
430 IF Z$="Y" OR Z$="y" OR Z$="N" OR Z$="n" THEN 440 ELSE 410
440 IF Z$="Y" OR Z$="y" THEN 450 ELSE 550
450 INPUT "THE INTERNAL ANGLE OF FRICTION OF THE ROCK IS (IN DEGREES)";N
460 PRINT
465 LET PI=3.1415926536#
470 LET O=N*2*PI/360
480 LET K=(1+SIN(O))/(1-SIN(O))
490 PRINT "THE TRIAXIAL STRESS FACTOR IS";K
500 PRINT
510 PRINT"_____________________________________________________"
520 PRINT
```

```
530 PRINT
540 GOTO 700
550 PRINT "SINCE THE INTERNAL ANGLE OF FRICTION OF THE ROCK IS UNKNOWN"
560 PRINT "THE TRIAXIAL STRESS FACTOR CAN BE ESTIMATED FROM SOME OF THE "
570 PRINT "VALUES CARRIED OUT ON BRITISH COAL MEASURES ROCKS."
580 PRINT
590 PRINT "        ROCK                    ESTIMATED TRIAXIAL STRESS FACTOR"
600 PRINT "        ----                    --------------------------------"
610 PRINT " WEAK MUDSTONE                              2 OR 3"
620 PRINT "        COAL                                  4"
630 PRINT "SANDSTONE (ANGULAR GRAINS)                  5 OR 6"
640 PRINT
650 INPUT "THE TRIAXIAL STRESS FACTOR IS";K
660 PRINT
670 PRINT "_____________________________________________________________"
680 PRINT
690 PRINT
700 PRINT "THE LABORATORY DETERMINED , UNCONFINED COMPRESSIVE STRENGTH"
710 INPUT "OF THE ROCK IS";C
720 PRINT
730 PRINT"_____________________________________________________"
740 PRINT
750 PRINT
760 PRINT "IN MANY SOFTER ROCKS,THE MODULUS OF ELASTICITY AND THE POISSON'S'
770 PRINT "RATIO MAY BE DIFFICULT TO OBTAIN.IF THESE VALUES CANNOT BE "
780 PRINT "OBTAINED,AN APPROXIMATION CAN BE MADE."
790 PRINT
795 PRINT "ARE BOTH THE POISSON'S RATIO AND THE MODULUS"
800 INPUT "OF ELASTICITY KNOWN?;ANSWER Y OR N";A$
810 PRINT
820 IF A$="Y" OR A$="y" OR A$="N" OR A$="n" THEN 840 ELSE 795
830 PRINT
840 IF A$="Y" OR A$="y" THEN 845 ELSE 870
845 INPUT "THE POISSON'S RATIO IS";V
848 PRINT
850 INPUT "THE MODULUS OF ELASTICITY IS";E
855 LET A=(1+V)/E
860 GOTO 1130
870 LET A=(4/C)/1000
900 PRINT
1130 PRINT
1140 PRINT "_____________________________________________________________"
1150 PRINT
1160 PRINT
1170 PRINT "THE COVER LOAD IS THE LOAD DUE TO THE OVERLYING MATERIAL"
1171 PRINT
1172 PRINT "THE COVER LOAD IS EQUAL TO THE DEPTH OF COVER"
1173 PRINT "MULTIPLIED BY AN ASSUMED CONSTANT =0.025"
1174 PRINT
1175 INPUT "THE DEPTH OF COVER IS (IN METERS)";Q1
1176 LET Q=Q1*0.025
1177 PRINT
1180 PRINT "THE COVER LOAD IS";Q
1190 PRINT
1200 PRINT "_____________________________________________________"
```

```
1210 PRINT
1220 PRINT
1230 INPUT "THE LINING RESISTANCE IS";P
1240 PRINT
1250 PRINT "------------------------------------------------------------"
1260 PRINT
1270 PRINT
1280 PRINT "ACCEPTED VALUES FOR A FACTOR RELATING LABORATORY STRENGTH"
1290 PRINT "TO IN SITU STRENGTH ARE GIVEN BELOW"
1300 PRINT
1310 PRINT " FACTOR                    DESCRIPTION"
1320 PRINT " ------                    -----------"
1330 PRINT "    1       STRONG MASSIVE UNJOINTED ROCK(INCLUDING CEMENT)"
1340 PRINT "    2       WIDELY SPACED JOINTS OR BEDDING PLANES IN STRONG ROCK"
1350 PRINT "    3       MORE JOINTED,BUT STILL MASSIVE ROCKS"
1360 PRINT "    4       WELL JOINTED AND WEAKER ROCKS"
1370 PRINT "    5       UNSTABLE SEAT EARTHS AND CLOSELY CLEATED ROCK SUCH AS COAL"
1380 PRINT "  6,7       WEAK ROCK IN THE NEIGHBOURHOOD OF FAULT ZONES"
1390 PRINT
1400 PRINT
1410 PRINT "A FACTOR RELATING LABORATORY STRENGTH TO IN SITU STRENGTH"
1420 INPUT "TAKING INTO ACCOUNT THE DEGREE OF JOINTING OR FRACTURING";F
1430 PRINT
1440 PRINT "------------------------------------------------------------"
1450 PRINT
1460 PRINT
1470 PRINT "AN AUGMENTATION OF THE LINING RESISTANCE IS GENERALLY"
1480 PRINT "ACCEPTED TO BE 0.1"
1490 PRINT
1500 PRINT "AN AUGMENTATION OF THE LINING RESISTANCE BROUGHT ABOUT "
1510 INPUT "BY THE COHESION OF THE YEILDED ROCK";R
1520 PRINT
1530 PRINT "------------------------------------------------------------"
1540 PRINT
1550 PRINT
1560 PRINT "IT IS PROPOSED THAT THE EXPANSION FACTOR BE ASSIGNED A VALUE"
1570 PRINT "OF 0.2,UNLESS IT IS SHOWN TO BE OTHERWISE."
1575 PRINT
1580 INPUT "THE EXPANSION FACTOR IS";X
1600 LET B=(K-1)*Q+C/F
1610 LET G=K+1
1620 LET H=2*Q-C/F
1630 LET J=(P+R)*(K+1)
1640 LET L=(2+X)/(K-1)
1650 LET AA=1/1000
1660 LET W=(D*A*(B/G))
1664 LET WW=(H/J)^L
1666 LET W=(W*WW)/AA
1670 PRINT
1680 PRINT
1690 PRINT "THE AMOUNT OF CLOSURE IS =";W;"MILLIMETERS"
1700 PRINT "------------------------------------------"
1710 PRINT
1720 PRINT "WOULD YOU LIKE A PRINT OUT OF THE VALUES AND"
```

```
1725 INPUT "RESULT?;ANSWER Y OR N";Y$
1730 IF Y$="N" OR Y$="n" OR Y$="Y" OR Y$="y" THEN 1740 ELSE 1720
1740 IF Y$="N" OR Y$="n" THEN 2100 ELSE 1750
1750 INPUT "TODAY'S DATE IS";R$
1760 INPUT "THE DATE THE DATA WAS COLLECTED IS";S$
1770 INPUT "THE LOCATION THE DATA WAS COLLECTED IS";T$
1780 LPRINT TAB(28);"DIAMETRIC CLOSURE CALCULATIONS"
1785 LPRINT TAB(28);"------------------------------"
1790 LPRINT " "
1800 LPRINT " "
1810 LPRINT TAB(10);"LOCATION DESCRIPTION:";T$
1820 LPRINT " "
1830 LPRINT TAB(10);"DATA COLLECTION DATE:";S$
1840 LPRINT " "
1850 LPRINT TAB(10);"REPORT GENERATION DATE:";R$
1860 LPRINT " "
1870 LPRINT " "
1880 LPRINT " "
1890 LPRINT TAB(10);"THE DRIVAGE DIAMETER IS";D;"METERS"
1900 LPRINT " "
1910 LPRINT TAB(10);"THE TRIAXIAL STRESS FACTOR IS";K
1920 LPRINT " "
1930 LPRINT TAB(10);"THE LABORATORY DETERMINED, UNCONFINED"
1935 LPRINT TAB(15);"STRENGTH OF THE ROCK IS";C;"MPa"
1940 LPRINT " "
1950 LPRINT TAB(10);"THE POISSON S RATIO IS";V
1960 LPRINT " "
1970 LPRINT TAB(10);"THE MODULUS OF ELASTICITY IS";E;"MPa"
1980 LPRINT " "
1990 LPRINT TAB(10);"THE COVER LOAD IS";Q;"MPa"
2000 LPRINT " "
2010 LPRINT TAB(10);"THE LINING RESISTANCE IS";P;"MPa"
2020 LPRINT " "
2030 LPRINT TAB(10);"THE FACTOR RELATING LABORATORY STRENGTH"
2035 LPRINT TAB(15);"TO IN SITU STRENGTH IS";F
2040 LPRINT " "
2050 LPRINT TAB(10);"THE AUGMENTATION OF THE LINING RESISTANCE"
2055 LPRINT TAB(15);"CAUSED BY COHESION OF THE YIELDED"
2057 LPRINT TAB(15);"ROCK IS";R;"MPa"
2060 LPRINT " "
2070 LPRINT TAB(10);"THE EXPANSION FACTOR IS";X
2080 LPRINT " "
2082 LPRINT " "
2084 LPRINT " "
2090 LPRINT TAB(10);"THE PREDICTED CLOSURE IS";W;"MILLIMETERS"
2095 LPRINT TAB(10);"------------------------------------------"
2100 CLS
2110 PRINT"WOULD YOU LIKE TO DO ANOTHER CALCULATION?;ANSWER Y"
2115 INPUT"OR N";W$
2120 IF W$="Y" OR W$="y" OR W$="n" OR W$="N" THEN 2130 ELSE 2110
2130 IF W$="N" OR W$="n" THEN 2140 ELSE 150
2140 CLS
2150 SYSTEM
2160 END
```